Progress on the VENUS ECR Ion Source

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Abstract

The VENUS ECR ion source, which is a third generation superconducting ECR ion source, is being constructed at Lawrence Berkeley National Laboratory for operation with the 88-Inch Cyclotron. It will operate with axial magnetic fields up to 4T and radial fields at the plasma wall up to 2T. The superconducting magnet structure, which consists of 3 solenoid coils and 6 race track coils forming a sextupole, achieved all of its design goals in tests in the fall of 1999. The cryostat and cryogenic system are under construction and feature two-stage cryo-coolers, liquid nitrogen cooling and high Tc current leads to reduce the heat load. Under normal operation it will not require liquid helium transfers. The source will initially operate at 18 GHz, but plans are underway to add a 28 GHz 10 kW gyrotron to fully exploit the high magnetic fields of the source. With the addition of a gyrotron to VENUS, the ion source will not only provide intense ultra high charge state beams for the cyclotron, but can also serve as a prototype heavy-ion source for the Rare Isotope Accelerator driver, which is in the planning stages.

The design of the source, status of its construction and optimization of its extraction system and beam transport through the low energy beam line are described below.

Introduction

VENUS (<u>V</u>ersatile <u>E</u>CR for <u>Nu</u>clear <u>S</u>cience) is a third generation Electron Cyclotron Resonance ion source designed to produce intense high charge state ions for injection into the 88-Inch Cyclotron[1,2]. The cyclotron is currently fed by the LBL ECR which began operation in 1985 and the AECR (1990) which was upgraded to the AECR-U in 1995. The major features of the three sources are given in Table 1, which illustrates the progression to higher magnetic field strengths and higher microwave frequencies. While the AECR-U can produce high intensities (79 eμA of Kr^{19+}) and high charge states (1 eμA of U^{47+}) higher performance from VENUS will provide new scientific opportunities at the cyclotron both in the heavy-element research with ions in the mass range from 50 to 150 and for nuclear structure with ions above mass 150. In addition VENUS can serve as a prototype ion source for the Rare Isotope Facility (RIA) driver linac[3]. The preliminary design for RIA has a 400 MeV heavy-ion driver linac which will require high intensity beams from the ion source up to several particle μA of U^{30+}.

Design of VENUS

VENUS is designed to incorporate an aluminum plasma chamber, multiple frequency heating at 18 and 28 GHz and strong radial and magnetic confinement. The aluminum plasma chamber provides a source of cold electrons through enhanced secondary electron emission which allows stable operation at lower neutral pressures. This is critical for the production of the highest charge states since charge exchange with neutrals limits the lifetime of very high charge state ions. Multiple frequency heating (at 10 and 14 GHz) was needed in the AECR-U for best production of very high charge state uranium beams[4]. However, it is the high magnetic fields which set VENUS apart from its AECR-U predecessor. The solenoid fields can operate up to 4 T at injection and 3 T at extraction and the sextupole will produce a field of 2 T at the plasma wall. Table 1 gives key parameters of the VENUS as well as the first two Berkeley sources.

Table 1: Comparison between LBNL ECR Ion Sources

	ECR	**AECR**	**VENUS**
Magnetic Field:Ampere-Turns	231,000	317,000	3,000,000
Magnetic Field:Peak Field	0.4 T	1.7 T	4 T
Microwave:Frequency	6.4 GHz	10, 14 GHz	18, 28 GHz
Microwave:Total Power	600 W	2,600 W	14,000 W
Extraction:High Voltage	10 kV	15 kV	30 kV

Figure 1 shows an elevation view of VENUS. The plasma chamber is constructed from an aluminum tube with gun-drilled water cooling channels to provide sufficient cooling for operation with 10 kW of 28 GHz microwave power. The plasma chamber will be pumped by a 1000 l turbo pump mounted on the injection end of the source. The design of the injection end provides for 3 off axis microwave feeds and two off axis ovens as well as a cooled biased disk on axis. The primary design goals were to minimize the microwave leakage out of the plasma chamber, maximize the pumping conductance and provide a biased disk for enhanced charge state production. The plasma chamber length is 50 cm corresponding to the distance between the main solenoid coils and 14 cm in diameter.

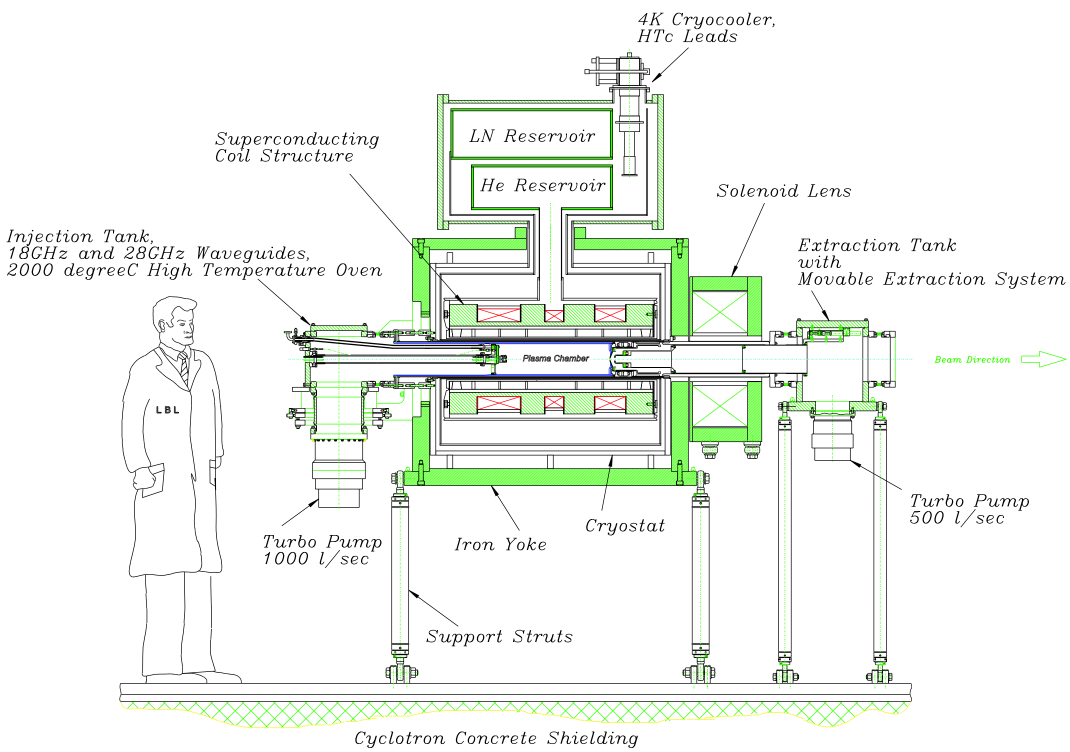

Figure 1: *Elevation view of VENUS*

Magnet and Cryogenic Systems

The magnetic fields are produced by a superconducting magnet structure consisting of three solenoid magnets and a race track superconducting sextupole structure. The two outer solenoids produce an axial magnetic mirror field, whose center strength can be lowered by the middle solenoid run with opposite polarity. The six racetrack coils are wound around a pole piece made of iron in the center and aluminum at each end. The primary challenge in the construction of the magnet structure was to develop a new clamping scheme to withstand the strong magnetic forces between the coils and eliminate coil movement leading to quenching. A key feature of the clamping was the development of expandable bladder system using thin stainless steel sheets which were inserted between the race track sextupole coils and then inflated with liquid metal[5]. The magnet assembly was tested in a 51cm ID cryostat. Initially the solenoids were tested without the sextupole over a variety of fields to simulate the maximum field at the coils and the axial forces that will be experienced in service. The solenoid coils reached full design fields with no quenches. A second set of tests included the sextupole coils and the quench behavior is show in Fig. 2. The sextupole experienced training quenches when tested by itself and when tested in progressively stronger solenoid fields. After 13 quenches it reached 505 A with the solenoids operating at design field. The design current for the sextupole with the solenoids at 100% is 438 A and the "short sample" current is 550 A.

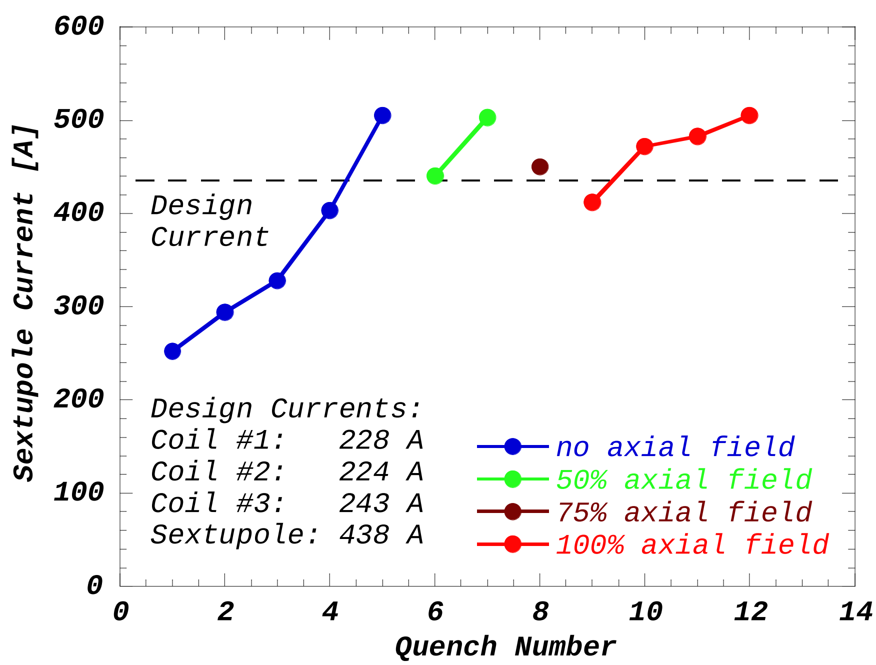

Figure 2: *Quench current of the sextupole vs. quench number*

The cryogenic system for VENUS is designed to operate at 4.2 °K with 2 cryo-coolers each providing up to 45 W of cooling at 50 °K and 1.5 W at 4 °K. Although it is anticipated that liquid helium will be used to speed the initial cool down, during stable operation the cryo-coolers will run in a closed loop mode without further helium transfers. High T_c superconducting links will be used between the 50 °K and 4 °K to minimize the heat leak through the 8 current leads. The cryostat is surrounded by a warm iron yoke and one of the main design challenges is to provide sufficiently strong links to support the magnet within the cryostat against the strong forces between the superconducting coils and the iron yoke. The links are fabricated from fiberglass and designed to keep the coil movement to less than 1 mm under the largest unbalancing force (12,500 lbs/link) which can occur if the large solenoid coil is operated at maximum current when the other solenoids are off.

Low Energy Beam Transport System

The low energy beam transport (LEBT) system for VENUS[6] is designed to transport more intense beams than the AECR-U LEBT since the extracted current from ECR ion sources scales roughly as the square of frequency. The transmission efficiency of the AECR-U LEBT decreases as the total extracted current increase above 2 mA for 10 kV extraction. An additional design consideration for the new LEBT comes from it serving as a prototype for RIA, where the LEBT must match the beam into an the relatively small acceptance of an RFQ. For these reasons the design of the extraction system and LEBT must provide high transmission and minimize the emittance growth due to space charge and aberrations.

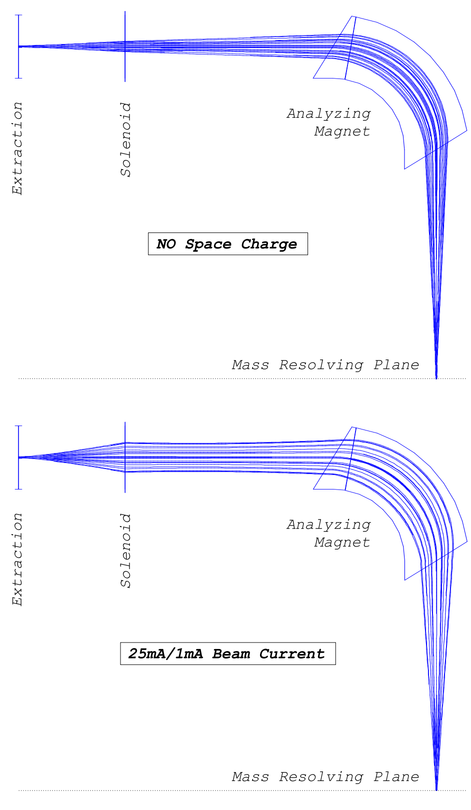

Figure3: *VENUS low energy beam transport simulation (GIOS) for two cases for different extracted beam currents (The second number refers to the current after the analyzing magnet)*

For the 88-Inch Cyclotron operation, the LEBT must be versatile enough to transport many different ion beams and charge states at varying extraction voltages. The tuning flexibility of the AECR-U LEBT comes from the insertion of a solenoid lens between the extraction and the analyzing magnet. In this scheme the solenoid lens focuses the extracted beam to the first focal point of the analyzing magnet. Ion optics simulations were used to analyze this type of LEBT with VENUS and they showed that a small waist in front of the analyzing magnet induces strong aberrations in high-space-charge ion beams. Further, the magnetic field of the solenoid lens needed focus the beam from VENUS at extraction voltages (up to 30 kV) would have required a 1.0 T field. Therefore, we decided to eliminate the waist in front of the analyzing magnet. Now the sole purpose of the solenoid lens is to adjust the angle of the beam going into the magnet (see Fig. 3 and 4). Since a single solenoid lens cannot control the actual beam diameter, a large magnet gap must be chosen to accommodate the highest anticipated beam intensities. To meet these requirements, a multipurpose analyzing magnet is currently in design and it will incorporate two quadrupole and two sextupole moments at the magnet edges with two more sextupole moments in the magnet center to compensate for higher order effects. 3D magnet calculations (Tosca 3D) are necessary to define the correct pole shape of the analyzing magnet. The resolution of the magnet will be $m/\Delta m \sim 100$, its beam radius 45cm and its pole gap 22cm.

Project Status

VENUS is scheduled to begin test operation at 18 GHz in the summer of 2001. The construction of the cryostat is underway at Wang NMR, Inc and should be completed in January. Installation of support equipment on the cyclotron vault roof is underway and construction of the source stand and other components has begun. The physics design of the LEBT will be completed shortly with the engineering design and fabrication expected to take about 8 months.

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